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WADC TECHNICAL REPORT 53-132

# THE DESIGN OF RECLAIMED LATEX FOAM PACKAGE CUSHIONING

The Third of a Series of Reports
on
Package Cushioning

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JANUARY 1954

WRIGHT AIR DEVELOPMENT CENTER

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# THE DESIGN OF RECLAIMED LATEX FOAM PACKAGE CUSHIONING

## The Third of a Series of Reports on Package Cushioning


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*Materials Laboratory*


*January 1954*

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Wright Air Development Center
Air Research and Development Command
United States Air Force
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## Foreword

This report was prepared by the Packaging Branch, Materials Laboratory under RDO No. 618-11(Ae), "Performance Evaluation of Cushioning Materials," Lt. R. B. Orensteen acting as project engineer. This report discusses the design of reclaimed latex foam cushioning, in much the same way that the second of this series of reports, WADC Technical Report 53-68, "A Technique for the Design of Glass Fiber Package Cushioning," discussed glass fiber cushioning. WADC Technical Report 53-43, "The Selection of Cushion Area in the Design of Package Cushioning," was the first of the series of reports on Package Cushioning.

## Abstract

A method of designing reclaimed latex foam cushioning from static data is presented. Design curves are provided for selecting density, thickness, and cushion area for economical cushion design. Recommended procedures are discussed for designing to optimum density, stress, and ratio/stress energy in a given situation.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

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## Introduction

The design technique for reclaimed latex foam package cushioning is similar to that of glass fiber as discussed in the previous report of this series. A wide range of cushioning properties can be achieved by changing the density, bonding material, etc. This report will consider density of material as a parameter in package cushion design. A method will be presented for choosing the density of material simultaneous with the selection of cushion area and thickness. The relationship between the package cushion design and cushion volume, cushion weight, and container cubage will be considered. In this manner a technique is provided for achieving the optimum cushion design criteria which will result in the most economical packaging.

## The Selection of Density and Thickness

In WADC Technical Report 53-43, it was shown that thickness and area of cushioning can be determined from the following:

$$t = \frac{hf}{Ge_f} \tag{1}$$

where t = thickness of cushioning
h = height of drop
G = fragility factor in g's
f = stress
$e_f$ = stored energy per unit volume of cushioning when stressed by f

and

$$f = \frac{WG}{A} \tag{2}$$

where A = area of cushioning (assumed flat)
W = weight of item

When the height of drop and the fragility factor are given, the thickness required becomes proportional to the ratio $f/e_f$. In plotting this ratio against stress f for a typical cushioning material, it was evident that there existed a stress for which $f/e_f$ was a minimum. Consequently, a minimum thickness of cushioning was possible, provided that the cushion area was selected so the stress corresponded to the minimum ratio value. Sometimes the procedure of adjusting the stress by changing the item-cushion contact area is advisable, sometimes not. The reader is referred to WADC Technical Report 53-43 for the criteria for changing cushion area to achieve minimum ratio values.

Figure 1 illustrates the variation in stress-strain curves which can be obtained with different densities of reclaimed latex foam cushioning. A ratio stress/energy curve can be derived for each of these stress-strain curves (WADC TR 53-43). A family of ratio curves for reclaimed latex foam cushioning is shown in Figure 2.

The points on the curves of Figure 2 which are of most interest are those which are least possible ratio values for any given stress. For example, assume a stress of 10 lb/sq. in. The least possible ratio value, for the individual curves shown, is about 5.1 and is on the 14.4 lb/cu.ft. density curve. A point on any other density curve for this stress would give a higher

ratio stress/energy. It has previously been pointed out that thickness is proportional to the ratio stress/energy. When one can choose the density, higher ratio values than 5.1 for the given stress are of only incidental interest. If the choice of density is not open, the problem is entirely different, and should be treated as in WADC Technical Report 53-43.

Notice that the least ratio value which was just determined for a 10 lb/sq. in. stress is not the minimum ratio point of the density curve on which it lies. Nevertheless, 5.1 is the least possible ratio value among all of those plotted for the given stress. Whereas the minimum points of the individual curves were of much concern when discussing a particular material or density of material, they are now apparently only of secondary importance.

The line of least possible ratio values, called an envelope line, is tangent to the family of curves in Figure 2. A line passing through the minimum points of the individual curves is clearly not a line of least possible ratio values. Consider where the envelope line of the family of curves is upward or downward. There will always be a ratio value on a lower or higher density curve which is more desirable than the minimum point of any curve one might choose. This more desirable point may not be the minimum point of its curve either; yet the ratio stress/energy can be smaller for this point than for the minimum point of some other curve. The limit of the least possible ratio values as the number of curves is increased to a very large number is the envelope line shown in Figure 2. Any other ratio stress/energy curve one might plot from the stress-strain curves for reclaimed latex foam cushioning would presumably be tangent to this line also. However, certain of the curves in Figure 2 are not tangent to the envelope line. This perhaps can be attributed to a variation other than density in some samples of material.

In the design of reclaimed latex foam cushioning, the envelope line of Figure 2 is very useful. Given the stress, one can choose the least of all possible ratio stress/energy values from the envelope line. The thickness can be calculated by substituting this ratio value in equation (1). The individual density curve which is tangent to the envelope line at the given stress would give the density required.

Rather than complicating Figure 2 by adding more individual ratio stress/energy curves, a different approach will be taken. Two design curves, Figures 3 and 4, will be used in place of the envelope line. The relationship between density and stress for points on the envelope line is more clearly shown in Figure 3. The stress values corresponding to the tangent points have been plotted against the densities of the materials whose curves are tangent at these points. A smooth curve has been drawn through these points. Thus it will be possible to estimate the density required for points on the envelope line where no individual curve for a density is shown. A curve showing least possible ratio values plotted against density is shown in Figure 4.

The design procedure using Figures 3 and 4 is simple. From Figure 3 one can select the density of material which, among all others, will require the least thickness of cushioning for the given stress (the cushion area being assumed as that of the item side itself). Once the density is chosen, the thickness is easily determined from Figure 4. The least ratio $f/e_f$ is read from the curve of Figure 4 and substituted in equation (1) to determine thickness.

Example:

Assume an item with fragility factor of 20 g's, weight of 50 lb., and area of side 50 sq. in. The stress from equation (2) is

$$f = \frac{50 \text{ lb.}}{50 \text{ sq. in.}} \times 20 = 20 \text{ lb/sq.in.} \qquad (3)$$

From Figure 3 the density corresponding to this stress is about 19 lb/cu.ft. From Figure 4 the ratio $f/e_f$ for this density is 5.4. The thickness of cushioning, substituting in equation (1) and assuming a 30 in. drop.

$$t = \frac{30 \text{ in.}}{20} \times 5.4 = 8.1 \text{ in.}$$

Warning - The above procedure cannot be reversed. Given a density of material, a ratio value can be determined from Figure 4. But thickness of cushioning can only be calculated from this ratio value in the event that the stress happens, or is altered by an area change, to correspond to this point. The procedure would be to determine the ratio value from the individual curve for that density of material. Then the procedure with regard to area selection can be followed as outlined in WADC Technical Report 53-43.

## The Selection of Cushion Area

To this point it has been assumed that the density and thickness only are selected. The cushion area has been given as equal to the flat area of the item itself on the side in question.

The envelope line of Figure 2 shows the relationship between stress and ratio stress/energy when designing for minimum thickness. As the stress and density increase, the ratio values decrease to a point and then increase. Since the fragility G is assumed given, the only method of changing the stress in equation (2) is by changing the area of contact between the item and cushion. To increase stress, reduce area; to reduce stress, increase area. By changing the area of reclaimed latex foam cushioning, one can obtain various ratio values.

The shape of the envelope line for reclaimed latex foam is similar to that of an individual curve. Therefore, the procedures for cushion area selection for an individual density of material should also apply when density is a parameter. This conclusion is valid only if the density is chosen properly. When the cushion area is varied, the stress is changed correspondingly. The density should be chosen using the new stress value. In other words, when cushion area is changed, density must be changed too.

The minimum ratio value of the envelope line will be called Js—e so as not to confuse it with Js which is the minimum ratio value or an individual curve. The stress corresponding to Js—e is called Bs—e. For the reclaimed latex foam with stress—strain curves as in Figure 1, Js—e is 4.7 and Bs—e is 5 lb/sq. in. The corresponding density is about 12 lb/cu.ft. Thus, by using a 12 lb/cu.ft. material with a cushion area such that the stress is 5 lb/sq.in., a minimum of cushion thickness will be required. However, minimum cushion thickness in not always desirable from an economic standpoint. There may be instances when the price of minimum thickness is too high in terms of cushion volume and/or container cubage. The following discussion will provide criteria for using Js—e and Bs—e in reclaimed latex foam package cushioning design.

In order to determine the optimum combination of cushion area, thickness, and density in any given situation, one must consider how these factors affect cushion volume, cushion weight, and container cubage.

To start with, assume that the cushion area is the same as the area of the item side in question. The stress is determined from equation (2). The results from changing the cushion area depend on where this stress is in relation to Bs—e. Assuming that the calculated stress is less than Bs—e, how is cushion volume and weight affected if the area is altered? Figure 5 shows what happens to cushion volume and weight as the stress is changed. It is evident that there would be no argument for increasing area and reducing stress when f is less than Bs—e. Reduced stress means higher ratio stress/energy and thus greater cushion thickness. It also means greater cushion volume and weight in addition to increased container cubage.

When f is less than Bs—e, there would be considerable benefit in reducing cushion area thereby increasing stress to Bs—e. By increasing the stress, the thickness requirement would be less as a consequence of the reduced ratio value. Cushion volume, cushion weight, and container cubage would be reduced. If the stress is increased beyond Bs—e, however, cushion thickness will be increased even though cushion volume will continue to be reduced. The disadvantage of increased cushion thickness is at once apparent — increased container cubage. The reduced cushion area generally contributes no savings in container cubage when this area is less than the item side in question. Whether to increase the stress beyond Bs—e is therefore a problem of economics — will the cost of the increased cubage be balanced by the savings of reduced cushion volume?

If the stress is greater than Bs-e, there would be little advantage in reducing stress to Bs-e. The container cubage would increase when the stress is reduced by increasing cushion area. The cushion area, now overlapping the item side, has a multiple increasing effect. The container cubage is increased on all sides. Cushion volume and cushion weight would increase as well. Cushion thickness has been reduced, but if this has not been reflected in reduced cubage, cushion weight, or cushion volume, then it is of little consequence.

If the stress is equal to Bs-e, an increase in stress might be beneficial if the cost of increased container cubage would be balanced by the savings in cushioning volume.

Table 1 summarizes the recommended procedures in cushion area selection for economic design.

Example:

W = 30 lb.
A = area of item side = 300 sq. in.
G = 15 g's

$$f = \frac{WG}{A} = \frac{30 \text{ lb.}}{300 \text{ sq. in.}} \times 15 = 1.5 \text{ lb/sq. in.}$$

The density as determined from Figure 6 is 8 lb/cu. ft. and the ratio stress/energy from Figure 5 is 5.3. The thickness is calculated from equation (1) as follows, assuming a 30 in. drop.

$$t = \frac{30 \text{ in.}}{15} \times 5.3 = 10.6 \text{ in.}$$

Since stress f is 1.5 lb/sq.in. and less than Bs-e, 5 lb/sq.in., there should be considerable advantage in adjusting the area to Bs-e. The area for optimum design would have to be found from equation (2).

$$A = \frac{30 \text{ lb.}}{5} \times 15 = 90 \text{ sq.in.}$$

The density at Bs-e is 12 lb/cu.ft. The thickness would be

$$t = \frac{30 \text{ in.}}{15} \times 4.7 = 9.4 \text{ in.}$$

The following table summarizes some of the benefits of area adjustment in this example:

| Density | Cushion Volume | Cushion Weight |
|---|---|---|
| 8 lb/cu.ft. | 1.8 cu.ft. | 14.2 lb. |
| 12 lb/cu.ft. | .5 cu.ft. | 6.0 lb. |
| Volume reduction | 1.3 cu.ft. | |
| Weight reduction | | 8.2 lb. |
| % Volume reduction | 72% | |
| % Weight reduction | | 58% |

A savings in cushion weight of 58% resulted from a reduction in cushion area from 300 sq. in. to 90 sq. in., with a corresponding adjustment in cushion density and thickness. This is in addition to savings in container cubage.

## Summary

Reclaimed latex foam cushioning exhibits a minimum static ratio stress/energy value. Consequently there is a particular density and stress which will provide a minimum thickness of cushioning. From an economic point of view, minimum thickness is not always a desirable objective. Often minimum thickness can be achieved only at the expense of increased cushion volume, cushion weight, or container cubage. Recommended procedures have been discussed for the proper choice of density, area, and thickness for economical latex foam package cushioning.

The reader is cautioned in the use of the data in this report. The procedures outlined will give only an approximation to the correct design. These approximations should be verified, when practicable, by test or service experience.

The fact that reclaimed latex foam has damping qualities might very well influence the extent to which static data can be used to determine requirements under dynamic conditions. But experience has shown that for reclaimed latex foam this damping factor introduces a margin of safety when designing from static data. This margin of safety is then available to compensate for errors introduced by various assumptions. For example, the thickness formula is an approximation and assumes that the fragility factor is very much greater than one and that the cushion displacement is small in relation to drop height. Also, the data are derived from materials from only two manufacturers, and a difference in fabrication technique or bonding material might change the stress-strain relationships. Furthermore, assumptions about fragility factors and drop heights are usually subject to considerable approximation.

Regardless of the material, where stress-strain information is available, the design approach used in this report might be considered for economical package cushion design.

| | |
|---|---|
| $f < Bs{-}e$ | Reduce cushioning area so that stress f equals Bs-e. Only increase f beyond this point if the additional cost of container cubage is compensated by the savings in cushion volume. This procedure will require a corresponding selection of density. |
| $f > Bs{-}e$ | Do not increase cushion area unless stress f is "near" bottoming. If near bottoming either reduce f or select another material. Only reduce cushion area if the additional cost of container cubage is compensated by the savings in cushion volume. |
| $f = Bs{-}e$ | Do not increase cushion area to reduce stress f. Only increase cushion area if the additional cost of container cubage is compensated by the savings in cushion volume. |

RECOMMENDED PROCEDURES IN THE DESIGN OF RECLAIMED LATEX FOAM PACKAGE CUSHIONING

Table 1

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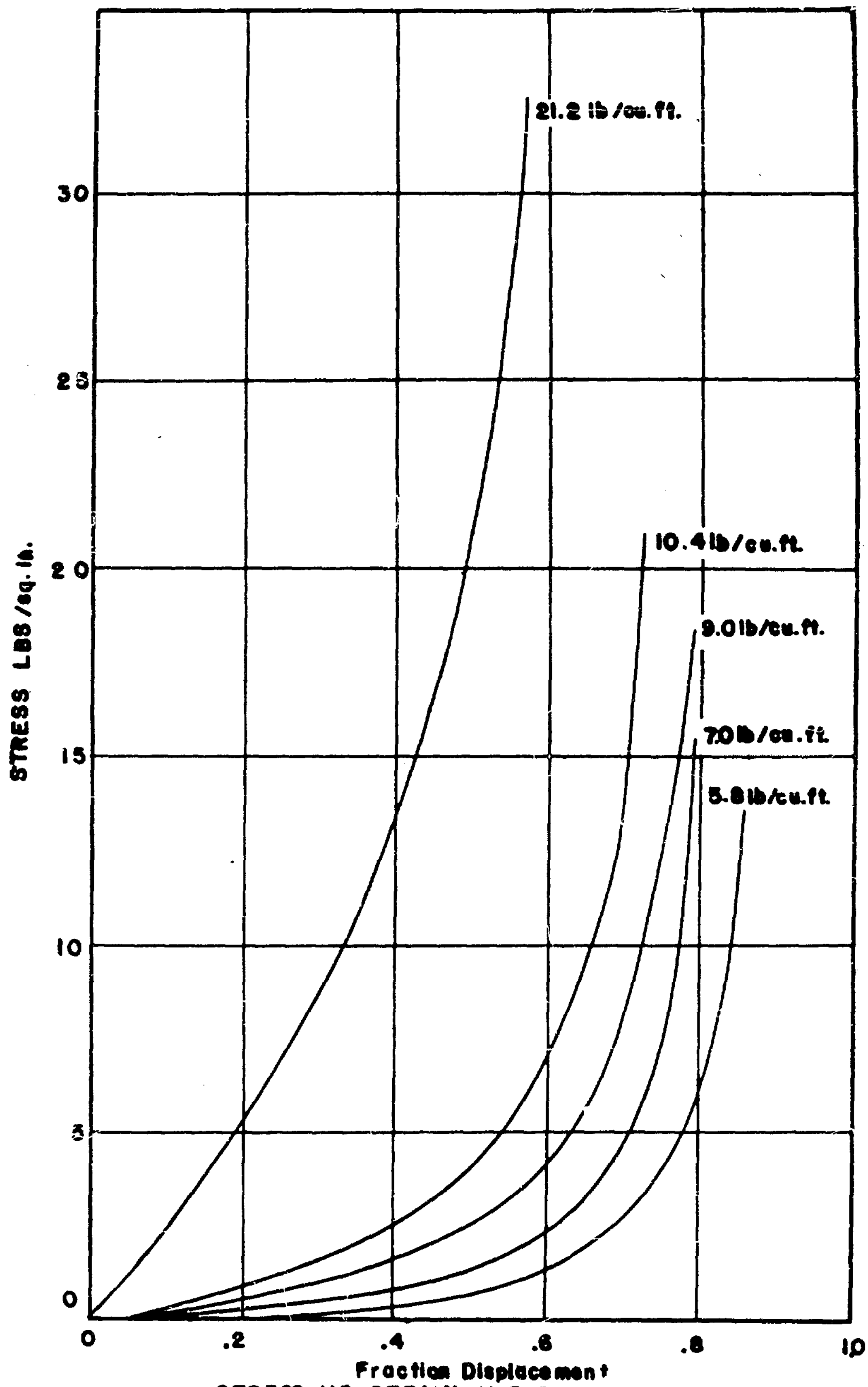
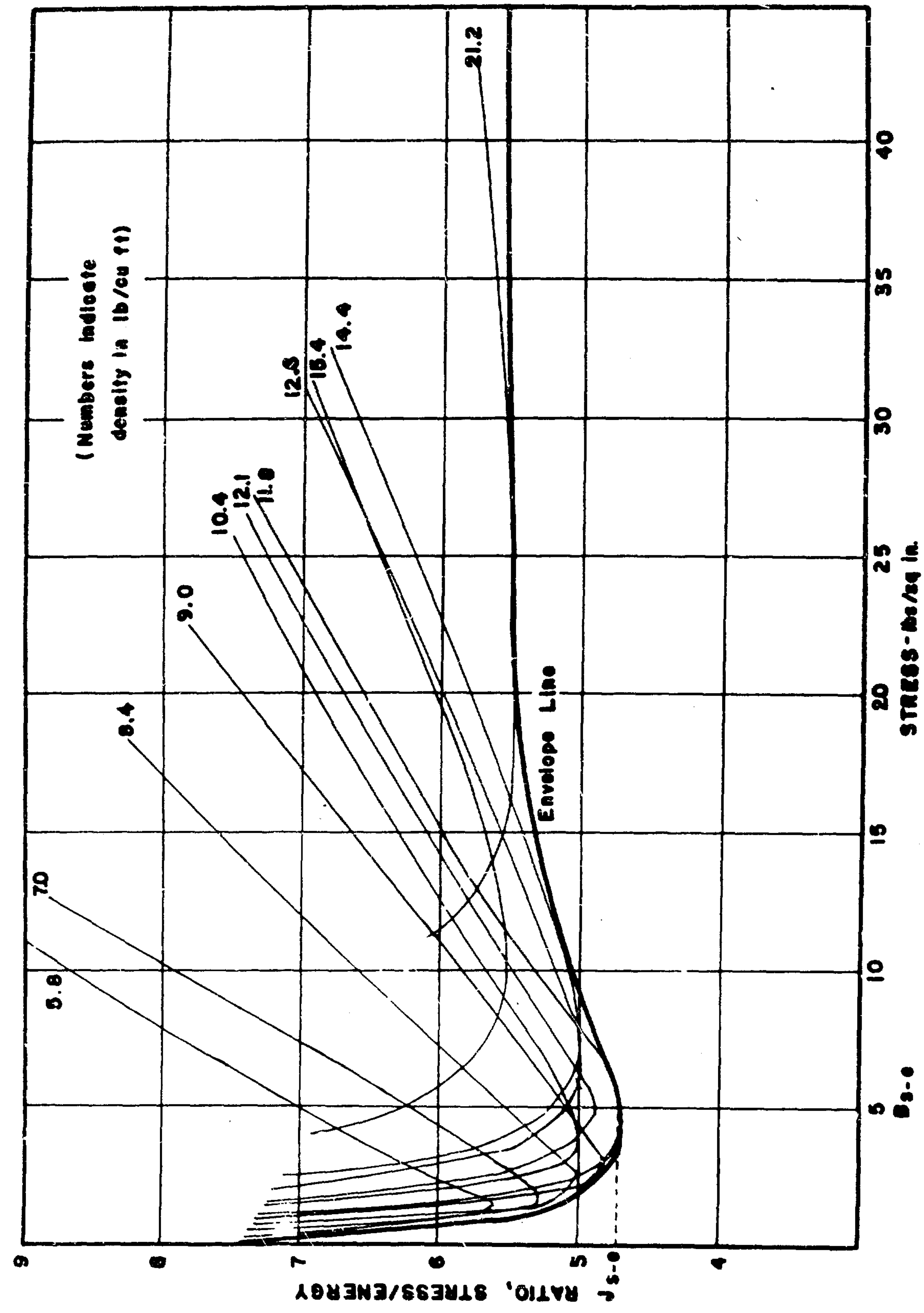
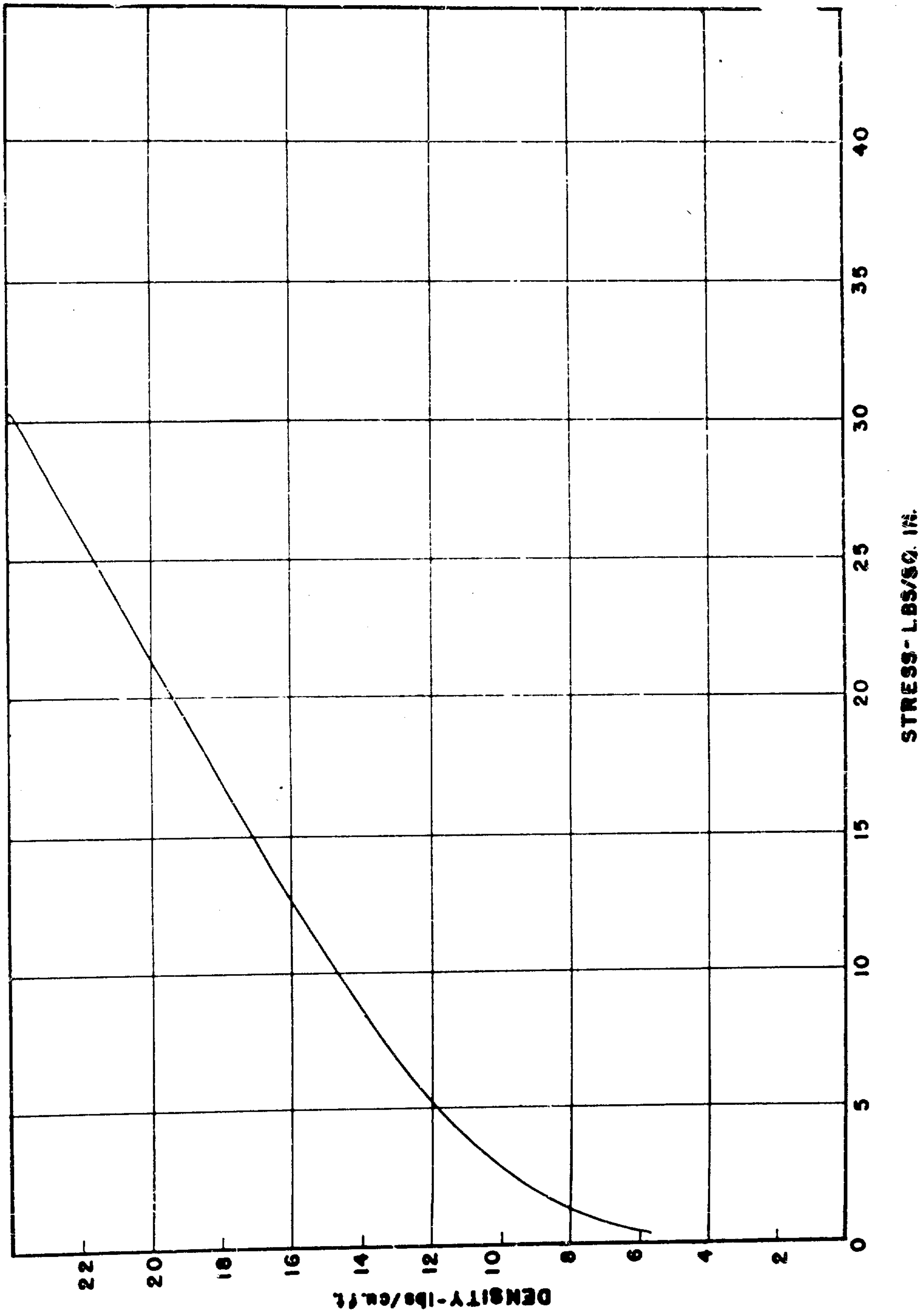


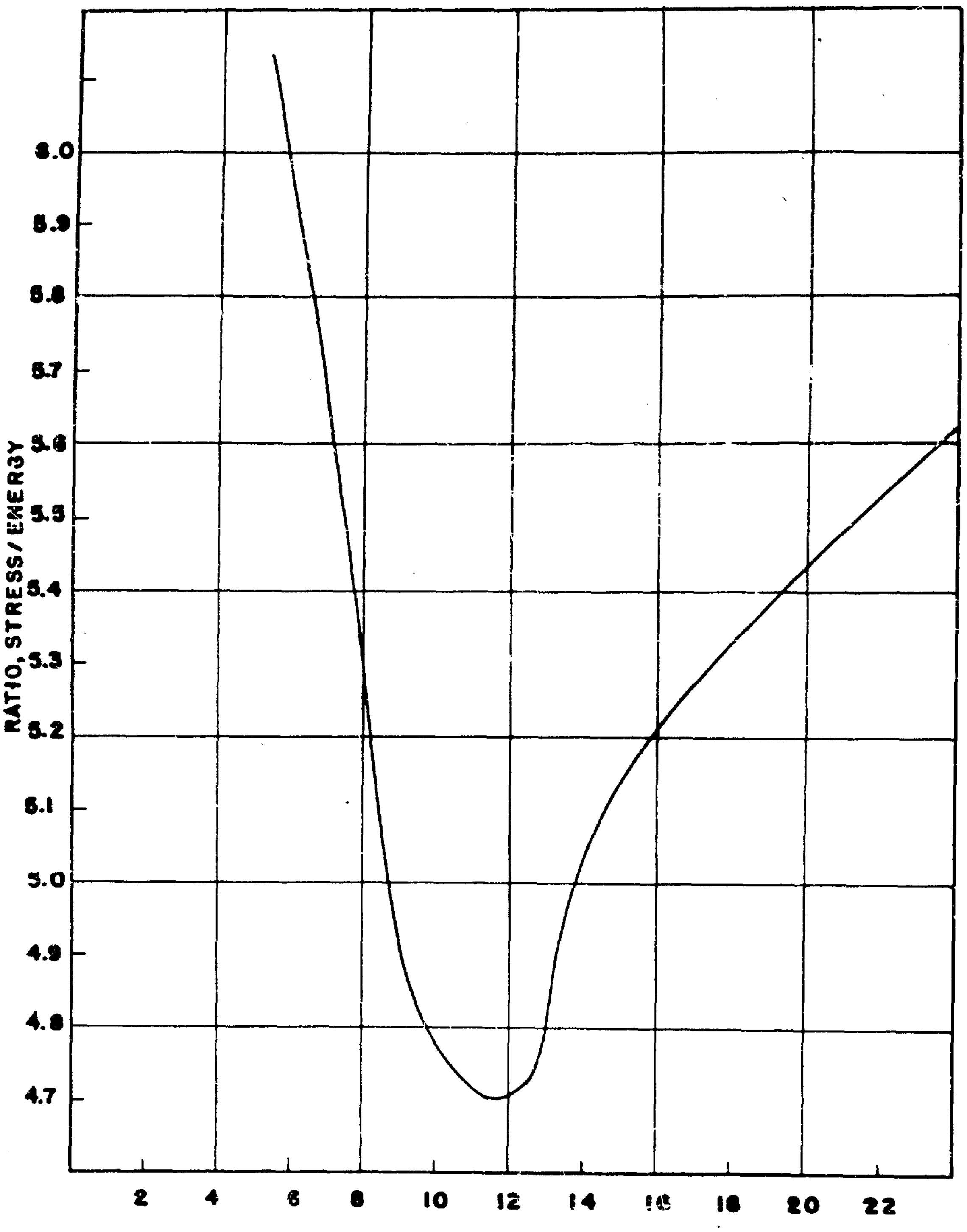

STRESS VS STRAIN VARIOUS DENSITIES
RECLAIMED LATEX FOAM
Figure 1



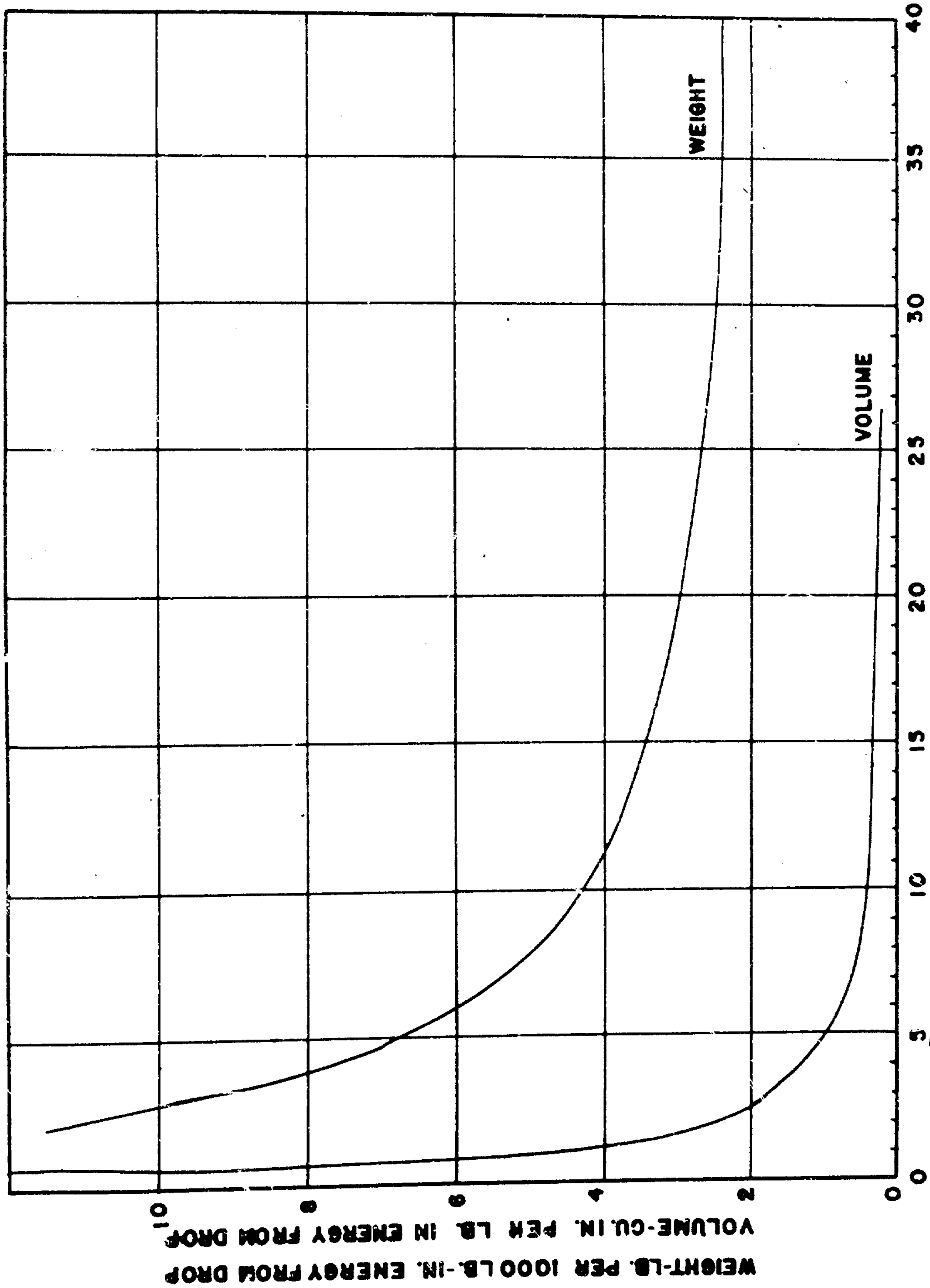

RATIO STRESS/ENERGY VS STRESS
RECLAIMED LATEX FOAM CUSHIONING
Figure 2




**DENSITY VS STRESS**
**RECLAIMED LATEX FOAM CUSHIONING**
Figure 3




DENSITY-lbs/cu.ft.
RATIO STRESS/ENERGY VS DENSITY
RECLAIMED LATEX FOAM CUSHIONING
Figure 4




VOLUME AND WEIGHT OF CUSHIONING VS. STRESS
RECLAIMED LATEX FOAM CUSHIONING
Figure 5